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THE MARINE PLIOCENE AND PLEISTOCENE STRATIGRAPHY OF THE COAST OF SOUTHERN CALIFORNIA.

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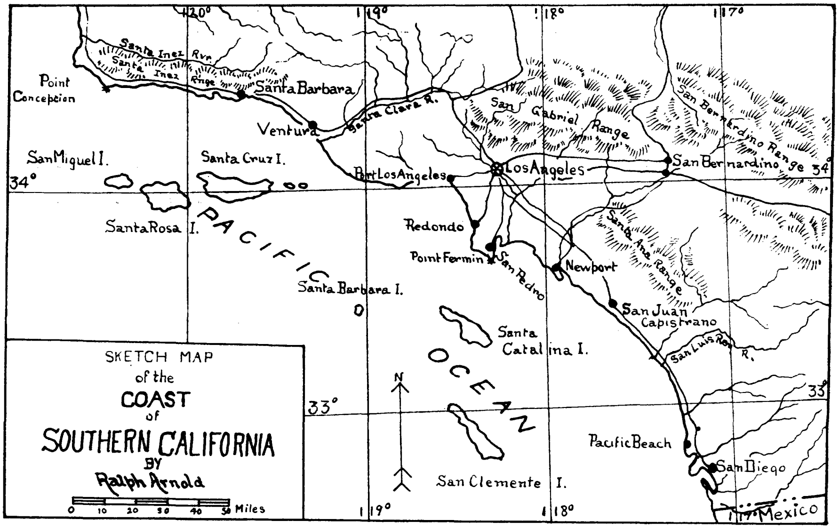
INTRODUCTION.

The best development of the marine Pleistocene of the Pacific coast of North America is found along the coast of southern

California, which extends from Point Concepcion on the north to San Diego on the south. A few references have been made by previous writers to the marine Pleistocene geology of western North America, but the inadequacy of their observations has failed to give a proper conception of the importance of the Pleistocene as developed along the southern California coast.



The field work upon which this paper is based has extended over a period of several years, during which time the writers have made a detailed study of the paleontology and stratigraphy of the Pleistocene and subjacent formations at San Pedro,[1] and have also visited and studied the formations at most of the localities from San Francisco to San Diego at which Pleistocene sediments are exposed. The deposits at San Pedro, being the best developed and most easily accessible, have been taken as the type series.

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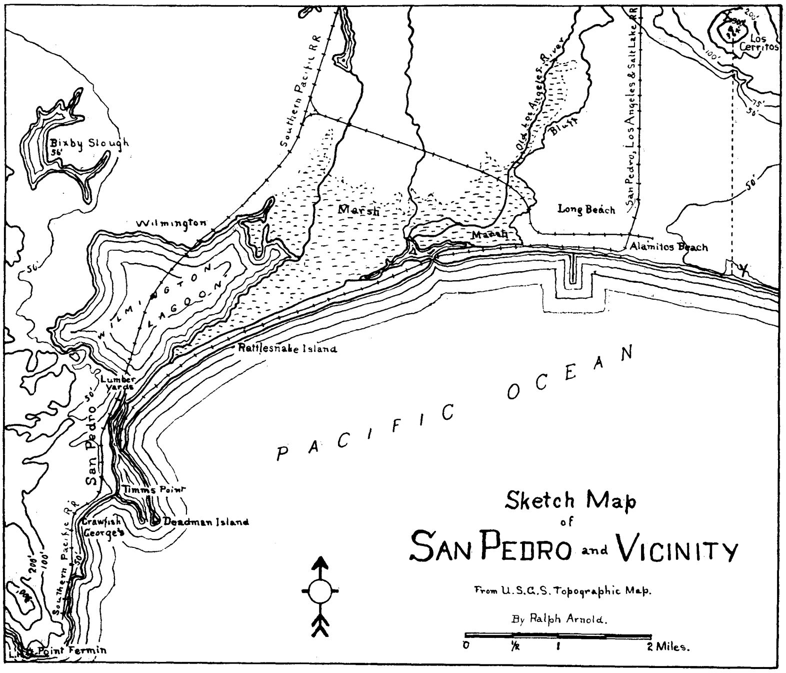
[1] The junior author has in press as a memoir of the California Academy of Sciences a paper entitled "The Paleontology and Stratigraphy of the Marine Pliocene and Pleistocene of San Pedro, with Notes on Similar Formations of the Adjacent California Coast."

SAN PEDRO — THE TYPE LOCALITY.

Topography.—The Pliocene and Pleistocene formations studied by the writers are confined to the lowest terrace of San Pedro Hill (see map of San Pedro and vicinity). This terrace extends from a point one-half mile east of Point Fermin to a bluff one-half mile north of the business portion of San Pedro. A sea cliff averaging fifty feet in height bounds the terrace on the south, east, and north. Half a mile southeast of San Pedro is Deadman Island, a small fragment of the lowest terrace, fifty feet in height with an area on top of about eight hundred square yards. All of the formations exposed in the immediate vicinity of San Pedro are represented at Deadman Island, and it is this section which is taken as the type.



General geology.— The oldest formation in the lowest San Pedro terrace is the Monterey or Miocene shale series. These shales, much contorted, are exposed along the sea cliff from Point Fermin to Timm's Point, and at Deadman Island, where they form the basement series. After the desposition of the Miocene shales the beds were elevated, contorted, and subjected to erosion. Following this a submergence took place during the Pliocene epoch, and a deposit of fine yellowish-brown, clayey sand was laid down on the surface of the eroded Miocene shales. The maximum thickness of this Pliocene at San Pedro is fifty feet.

In post-Pliocene times this sandstone was elevated and subjected to erosion; the Deadman Island and Timm's Point brown sands being all that is left of the Pliocene near San Pedro.

A later submergence brought the surface of the Pliocene again below sea level and deposits of fine gray sand, fossiliferous in places, were laid down on it. The maximum thickness of the gray sand formation at San Pedro is fifty feet. This gray sand formation rests unconformably on the Pliocene at Deadman Island, but is probably conformable with the Pliocene at Timm's Point. On account of its fauna, lithologic characteristics, and unconformable position on beds of late Pliocene age the gray sand formation, called the lower San Pedro series, is thought to be of Pleistocene origin.

A period of uplift more or less pronounced followed the deposition of the lower San Pedro series. This uplift brought about conditions favorable to the formation of lagoonal, sand dune, and shore deposits. These deposits, which are called the upper San Pedro series, consist of coarse gravels and sands, which are characterized by the abundance of their fossil contents, by false bedding, and by indications of the changing conditions which prevailed during the period of their deposition. Evidence which indicates that the upper San Pedro series rests unconformably upon the subjacent formations is found at all the outcrops of this formation which have been examined by the writers. The upper San Pedro gravels and sands rest upon the Miocene shales at Crawfish George's, on the Pliocene at Timm's Point, and on the lower San Pedro series at Deadman Island and the

San Pedro bluff, reaching its maximum thickness of twenty feet at the last locality.

An elevation which raised the San Pedro deposits to near their present level occurred after the deposition of the upper San Pedro series; then after remaining at a constant level for some time another small uplift took place, which left the beds in their present position. This last period of rest and subsequent elevation is evidenced by a raised beach formation four feet thick and six feet above the sea level on the north end of Deadman Island (see Fig. 1).

Pliocene.—The Pliocene at Deadman Island (see Fig. 1 and Plate I) consists principally of a series of fine brown clayey sand layers having a dip toward the north of eight to ten degrees and a thickness of forty-five feet. The bottom layer of this series, which rests on the eroded surface of the jointed Miocene shale, is a fossiliferous stratum twelve inches thick of water-worn shale pebbles and sand. Many of the shale pebbles, and the surface of the eroded shale, show worm and pholas borings. About eight feet of fine yellowish-brown, rather incoherent, clayey sand rests on the gravel stratum. Well-preserved fossils are abundant in some parts of the clayey stratum. Four feet of hard, fine, porous, brown sandstone overlie the clayey stratum. Fossils are common in this hard bed, the most fossiliferous places being the harder, due to the cementing effect of the lime from the shells. On account of the great abundance of *Thyasira* (= *Cryptodon*) *bisecta* in this hard stratum it has received the local name of "Cryptodon bed." Twenty-five to thirty-five feet of faintly laminated brown sandstone overlie the Cryptodon bed. These uppermost brown sands are characterized by beautiful specimens of *Pecten caurinus*, *Lucina acutilineata*, and *Panomya ampla*.

The fauna of the Deadman Island Pliocene is somewhat similar to the fauna which is now living in twenty to fifty fathoms off shore from San Pedro. The Pliocene sediments are also analogous to the mud and fine sand now found on the bottom off the San Pedro shore. It is, therefore, safe to assume that

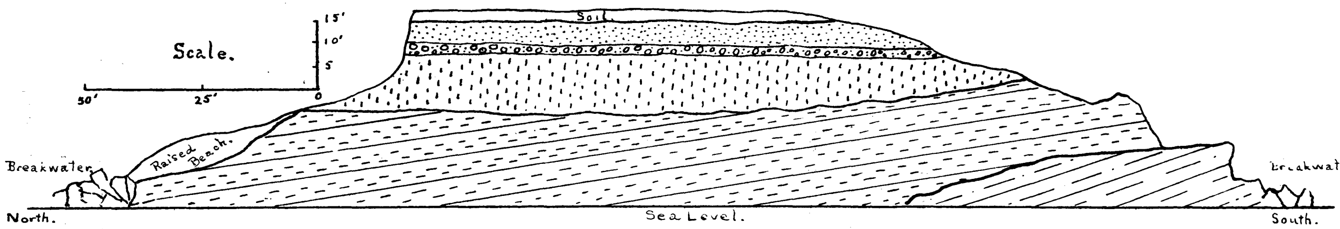


Fig. 1. Section through Deadman Island.

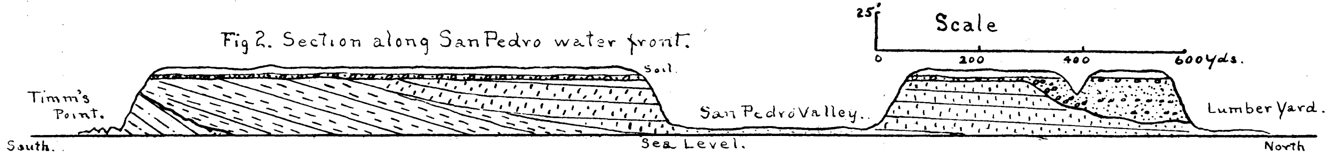


Fig 2. Section along San Pedro water front.

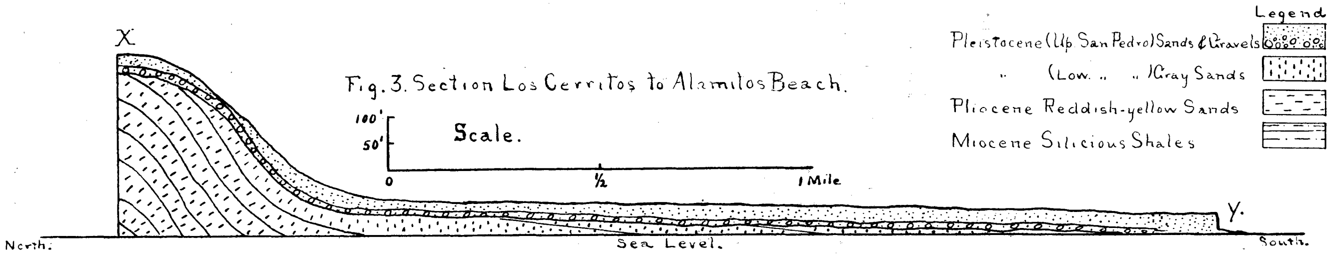


Fig. 3. Section Los Cerritos to Alamitos Beach.

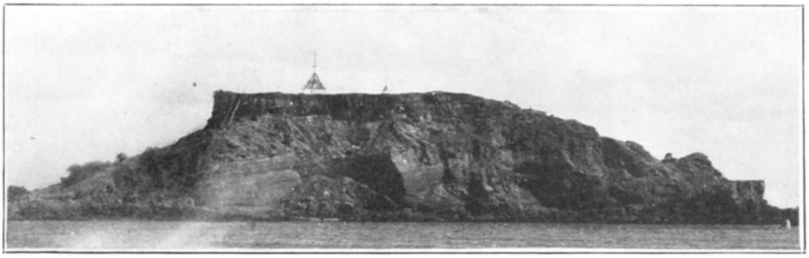


PLATE I*a*.—West face of Deadman Island, looking east, showing Miocene, Pliocene, and Pleistocene formations (see Fig. 1 for explanation).

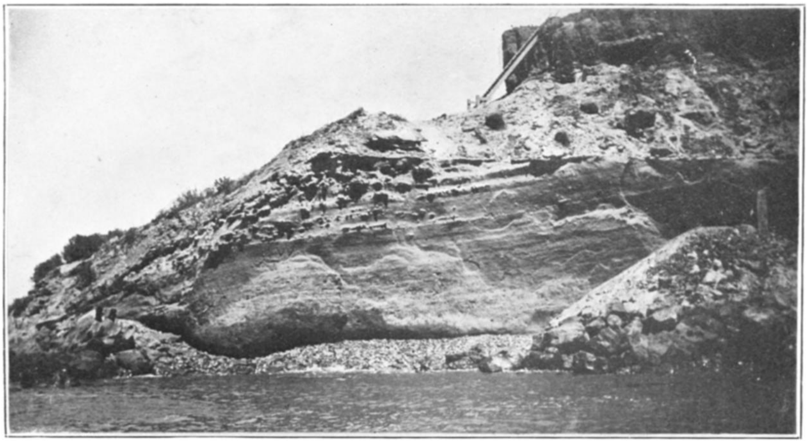


PLATE I*b*.—North end of Deadman Island, looking east, showing nonconformity between Pliocene and lower San Pedro (Pleistocene) gray sands (see fig. 1 for explanation).

the Deadman Island Pliocene was deposited under conditions somewhat analogous to those now prevailing in the ocean off San Pedro at depths of from twenty to fifty fathoms. There is a marked difference, however, between the Pliocene fauna and that now living off San Pedro, the former being characterized by the abundance of the individuals and species which are now found living only far north of San Pedro. To state it more precisely, out of the Pliocene fauna of eighty-seven species, 18.5 per cent. are found living now only north of San Pedro, and nearly all of the remaining species yet living show a decided predilection for boreal or subboreal conditions. The occurrence in large numbers in the Deadman Island Pliocene of *Pecten caurinus*, *Panomya ampla*, *Thyasira bisecta*, *Pecten hericeus*, *Lucina acutilineata*, *Natica clausa*, several species of *Trophon* and northern *Pleurotomidæ*, and other boreal and subboreal forms leads to the conclusion that these Pliocene strata were deposited in water much colder than that which is now found in the vicinity of San Pedro. Boreal or subboreal conditions so near the shore imply boreal or subboreal climatic conditions on the land, at least near the ocean. This being true, it is safe to assume that, during the latter part of the Pliocene epoch, the climate was much colder on the coast of southern California than it is at present.

The lowest, or brown sandstone, series of Deadman Island is called Pliocene for several reasons. First, it overlies unconformably the Miocene shales, from which it differs widely both lithologically and faunally. Second, it contains a fauna over 12 per cent. of which are extinct species, and many of the remaining species are those now found living only in places remote from San Pedro. This evidence precludes any possibility of its being Pleistocene. Third, the general aspect of the fauna is quite similar to that of the British Crag (Pliocene). That the Deadman Island Pliocene belongs to the latter part of that epoch is evidenced by its fauna, which gradually grades into that of the typical Pleistocene through that of the overlying lower San Pedro (Pleistocene). The gap between the Deadman Island Pliocene and Pleistocene is distinct, though not wide.

Dr. Dall[1] says of this Pliocene horizon: "It appears that on Deadman Island, near Point Fermin, at least three distinguishable strata appear, the uppermost of which is certainly Pleistocene, while the others are Neocene, and the middle layer probably Pliocene."

The brown Pliocene sandstone formation outcrops at Timm's Point (see Fig. 2), on the western side of San Pedro Bay. Here it lies unconformably on the Miocene shales as at Deadman Island; but its stratigraphic relation with the overlying lower San Pedro (Pleistocene) beds is not so easily determinable, although the faunal break between the two formations is as pronounced as at Deadman Island.

Pleistocene: the San Pedro series.—The evidence brought forward in this paper demonstrates that most of the marine Pleistocene as developed on the Pacific coast is represented by the strata of Deadman Island and San Pedro. The writers, therefore, propose the name San Pedro series for all of the strata of Deadman Island and San Pedro lying stratigraphically above the brown Pliocene sandstone formation and below the raised beach formation of Deadman Island. The San Pedro series may be divided into two distinct horizons, a lower and an upper, separated at all points in the vicinity of San Pedro by an unconformity.

Lower San Pedro series.—A stratum of gray sandstone averaging about twelve feet in thickness rests unconformably upon the brown Pliocene sandstone at Deadman Island (see Fig. 1). This gray sandstone is incoherent in some places but very firmly cemented in others, the harder portions usually being the more fossiliferous. No bedding is visible in the gray sand, but the formation lies nearly horizontal. This lower San Pedro stratum at Deadman Island, and also the contemporaneous strata in the San Pedro bluffs (see Fig. 2), as indicated by their lithologic characters and fauna, were deposited in water shallower than that in which most of the underlying brown Pliocene strata were laid down. The sediments consist for the most part of medium grained gray sands, such as are being deposited at the present time quite near shore off San Pedro. The abundance in the lower San Pedro deposits of certain species which live only between tides also offers evidence of deposition of the strata near the shore.

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[1] W. H. DALL and G. D. HARRIS, *Correlation Papers: Neocene. U. S. Geol. Surv., Bull. No. 84*, p. 216, 1892.

The fauna of the lower San Pedro series is one of transition from the boreal or subboreal fauna of the late Pliocene to the semi-tropical fauna of the upper San Pedro series. Two causes account for this change: (1) The deposits being laid down in shallower water than that in which the Pliocene sediments were deposited would necessarily contain fewer of the colder, deeper water forms of the Pliocene; and (2) the lower temperature prevailing during the latter part of the Pliocene epoch was giving place to warmer conditions, which caused the boreal species to migrate and brought in more of the species which commonly inhabit warm waters. Of the fauna of nearly 250 species found in the lower San Pedro series, over 17 per cent. are now found living only north of San Pedro. This percentage is only a little lower than that of the northern species found in the Pliocene, (the latter being 18.5 per cent.), and indicates, considering the fact that the lower San Pedro beds are shallower water deposits than those of the Pliocene, that the climatic conditions had changed but little during the period, intervening between the deposition of the Pliocene and the overlying lower San Pedro series.

The evidence afforded by several species in the lower San Pedro series (about 4 per cent. of the fauna of that series), which are now found living only south of San Pedro, shows that the conditions were changing from cold to warm. Besides the distinctly northern forms which either disappear or become scarce in the period between the Pliocene and lower San Pedro, there are many species now more commonly found in northern waters, which, though common in the Pliocene, become rarer in the Pleistocene; while species showing a predilection for southern conditions become common in the fauna of the latter period.

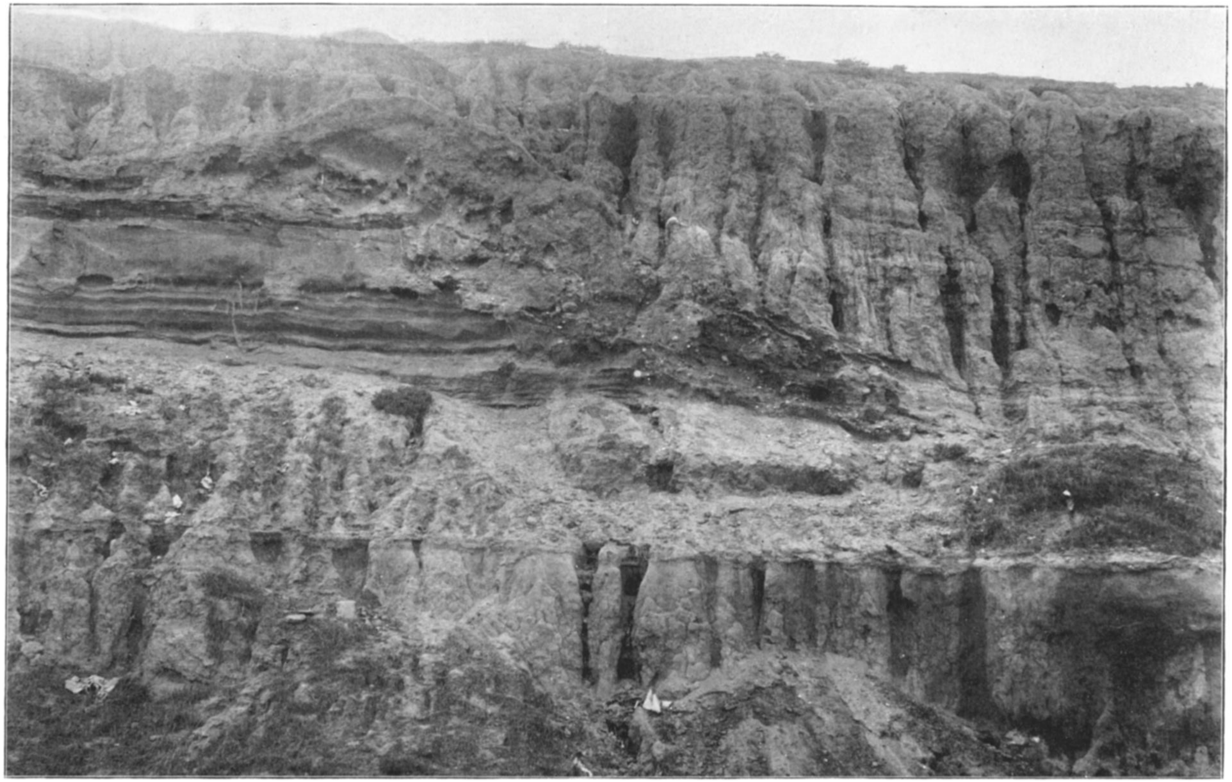
All of the evidence shows that the conditions were changing from boreal toward subtropical during the time just preceding and during the deposition of the lower San Pedro series ; but boreal conditions still predominated.

This series is placed in the Pleistocene primarily upon paleontologic evidence. The low percentage of extinct species and the occurrence of the three living echinoderms *Strongylocentrotus purpuratus*, *S. franciscanus*, and *Echinarachnius excentricus* offers strong evidence of the Pleistocene age of this series, the three species of echinoderms having never been found in any of the beds on this coast commonly accepted as Pliocene. The general aspect of the deposits, the state of preservation of the fossils, and the unconformable position of the lower San Pedro series on upper Pliocene beds strengthen the faunal evidence.

These beds are exposed in the bluffs north of Timm's Point (see Fig. 2), where they rest on the brown Pliocene sandstone and are overlain unconformably by the upper San Pedro gravels. There is some doubt as to the relation between the Pleistocene and the underlying Pliocence in these bluffs, although most of the available evidence is in favor of the conformability of the two formations.

Upper San Pedro series.—The gray sandstone of the lower San Pedro series at Deadman Island (see Fig. 1) is overlain unconformably by a three-foot stratum of fossiliferous gravel hardened by lime, above which are about seven feet of fine sand. This gravel stratum and the overlying sand makes the upper San Pedro series at Deadman Island. The gravel stratum is continuous over nearly the whole of the lower, or fifty-foot, San Pedro terrace, and at nearly every exposure it is seen to lie unconformably upon the subjacent beds. This evidence shows that the deposition of the upper San Pedro beds followed a period of erosion. The best development of the upper San Pedro series is found in the bluff at the lumber yard north of San Pedro (see map of San Pedro, and also Fig. 2), where the alternating fossiliferous beds of gravel and sand attain a thickness of twenty feet.

Plate II.



San Pedro. Peculiar nonconformity between lower and upper San Pedro series (Pleistocene) beds, in water front bluff south of lumber yard (photographs by Dr. H. W. Fairbanks).

The deposits of the upper beds in the vicinity of San Pedro consist for the most part of coarse gravels and sands which show alternating dune and water bedding, and have the appearance of having been laid down during a period of rapidly changing conditions.

The fauna of the upper beds is southern in character, and, as would be expected, approaches more nearly the present living fauna of the San Pedro region. Since the fauna of the upper beds inhabited shallower water than that in which either the Pliocene or lower San Pedro faunas lived, one would expect to find in it fewer of the cold water forms and more of the species found between tides and in the warm shallow waters of lagoons. Such is the case, but further, it is a noticeable fact that in the upper beds over 14 per cent. of the fauna are species which are now found living only south of San Pedro. This is not only true, but of those species found in the upper beds which are still living at San Pedro, a great majority are forms which are commoner in the waters south of that place.

Although over 6 per cent. of the upper San Pedro fauna are found now living only north of San Pedro, these northern species are only very rarely found in this formation. On the other hand most of the distinctly southern forms and those which, though now living at San Pedro are commoner further south, are commoner in the upper beds, thus giving it a semitropical aspect. Such species as *Cardium elatum*, *Arca labiata*, *Pecten dentatus*, *Mactra exoleta*, *Venus gnidia*, *Murex leeanus*, *Eupleura muriciformis*, *Cancellaria tritonidea*, and *Bulla punctulata* give this fauna its southern character. The evidence afforded by the southern forms outweighs the evidence of the northern species in another respect, for it would require a great change in conditions from those prevalent during later Pliocene times to cause these southern species to migrate northward to the San Pedro region; while this same change in condition would not so materially affect the northern species, for they could simply migrate into deep water where the conditions would more nearly approximate the boreal. This latter has been the case with such species as *Lucina acuti-*

lineata, *Chrysodomus tabulatus*, *Solariella cidaris*, and *Solariella peramabilis*, which now inhabit northern waters near shore, but which have been dredged in the deep water between Catalina Island and the mainland.

The upper San Pedro series is separated from the lower for three reasons: (1) on account of the unconformity existing between the two; (2) on account of the difference in their lithologic characters, the former consisting of gravels or coarse sands, while the latter is made up wholly of rather fine gray sands; and (3) because of the great difference in the faunas of the two; that of the former being one indigenous to warm water, that of the latter, one which is now found living where sub-boreal conditions prevail.

The occurrence of Pleistocene deposits younger than the upper San Pedro beds at several points along the coast, and the crustal movements and elevation of the coast that have taken place at several places since the deposition of the upper San Pedro beds indicate that quite a long period of time has elapsed since the latter were laid down.

A raised beach on the north end of Deadman Island (see Fig. 1), six feet above sea level and four feet thick affords evidence of another period in the Pleistocence. The shells in this deposit are the same as those found in the beach at Deadman Island at the present time, and the most of them retain their original coloration. This raised beach represents a very late Pleistocene horizon.

Post-Pleistocene Deposits.—The marine deposits of Deadman Island and the San Pedro terrace are overlain by alluvial deposits which contain large quantities of shells in certain places. These shell heaps are ancient Indian kitchen middens. Shells of a kind that would be used for food, such as *Haliotis cracherodii*, *Pecten æquisulcatus*, *Chione succincta*, *Tivela crassatelloides*, *Tapes staminea*, *Saxidomus aratus*, and others are found mixed with pieces of charcoal, flint chips and animal remains in these ancient accumulations. These Indian kitchen middens are often mistaken for fossil deposits, especially the one at Port

Harford, San Luis Obispo county, where the deposits of shells in the adobe soil attain a thickness of over six feet.

SAN DIEGO.

General geology.—Next to San Pedro, the best development of the marine Pleistocene of Southern California is found in the vicinity of San Diego. The geologic history of San Diego has been somewhat similar to that of the San Pedro region. During late Pliocene times the territory now occupied by San Diego Bay and the region to the northwest was occupied by an arm of the sea in which were deposited several hundred feet of coarse gravels, and these in turn were overlaid by fine grained sandstones. An uplift took place at the close of the Pliocene or in early Pleistocene times, followed by a period of erosion during which the terrace or mesa which extends from San Diego to Pacific Beach was planed off. Following the period of uplift a slight depression took place, and the gravels and sands of the upper San Pedro series (Pleistocene) were laid down on top of the eroded Pliocene sandstone. Since the deposition of the latest beds an uplift of at least fifty feet has taken place.

Pliocene.—The writers have examined the Pliocene strata at Pacific Beach, and near the Russ School (San Diego well). The Pliocene at Pacific Beach makes the lower part of the sea cliff which begins at Ocean Front and extends northward for at least a mile and a half (see Fig. 4). Two hundred feet of yellowish-brown sandstone, dipping south at an angle of about 10 degrees and overlain unconformably by Pleistocene gravel, are exposed in this section. The upper layers of the sandstone are fossiliferous, while the lower portion, which rests on an unknown thickness of coarse gravels, is without fossils.

There are two horizons in the fossiliferous section of the sandstone which may be separated upon paleontologic evidence. The lower horizon comprises all of the exposed fossiliferous beds with the exception of the uppermost three or four. It is characterized by a unique fauna among which are found the following species which are not known outside of the San Diego province: *Pecten expansus, Pecten subventricosus, Opalia varicostata* and *Opalia anomala.* This lower horizon is correlated with the Deadman Island Pliocene. The upper horizon is characterized by *Pecten hemphilli, Crepidula grandis, Macoma secta, Echinarachnius excentricus* and *Strongylocentrotus purpuratus*, and is correlated with the lower San Pedro series (Pleistocene).

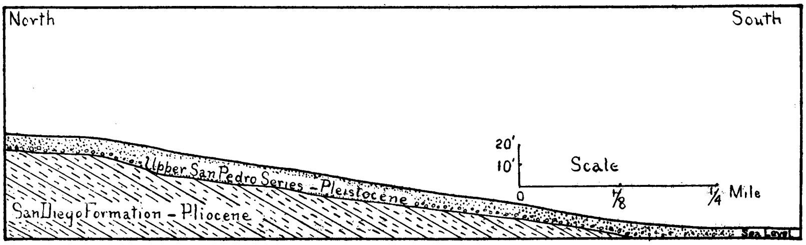

North
South
20'
10'
Scale
0
1/8
1/4 Mile
Upper San Pedro Series - Pleistocene
San Diego Formation - Pliocene
Sea Level

FIG. 4.— Section along Pacific Beach, near San Diego, showing the relation between the San Diego formation (Pliocene) and the upper San Pedro series (Pleistocene).

A formation similar to that of the Pacific Beach Pliocene outcrops near the Russ School, in the northern part of San Diego. The San Diego well, which is located just south of this outcrop, gives an instructive section of this Pliocene series. The well is at the bottom of a ravine (see Fig. 5), the sides of which are of strata containing a fauna similar to that of the upper Pliocene horizon at Pacific Beach. The strata above the well dip gently south toward San Diego Bay. The well is 149 feet deep,[1] and

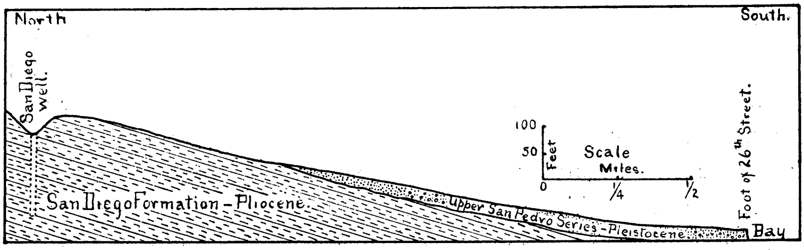


FIG. 5.— San Diego. Section from San Diego well to bay at foot of Twenty-sixth street, showing relation of San Diego formation (Pliocene) to upper San Pedro series (Pleistocene).

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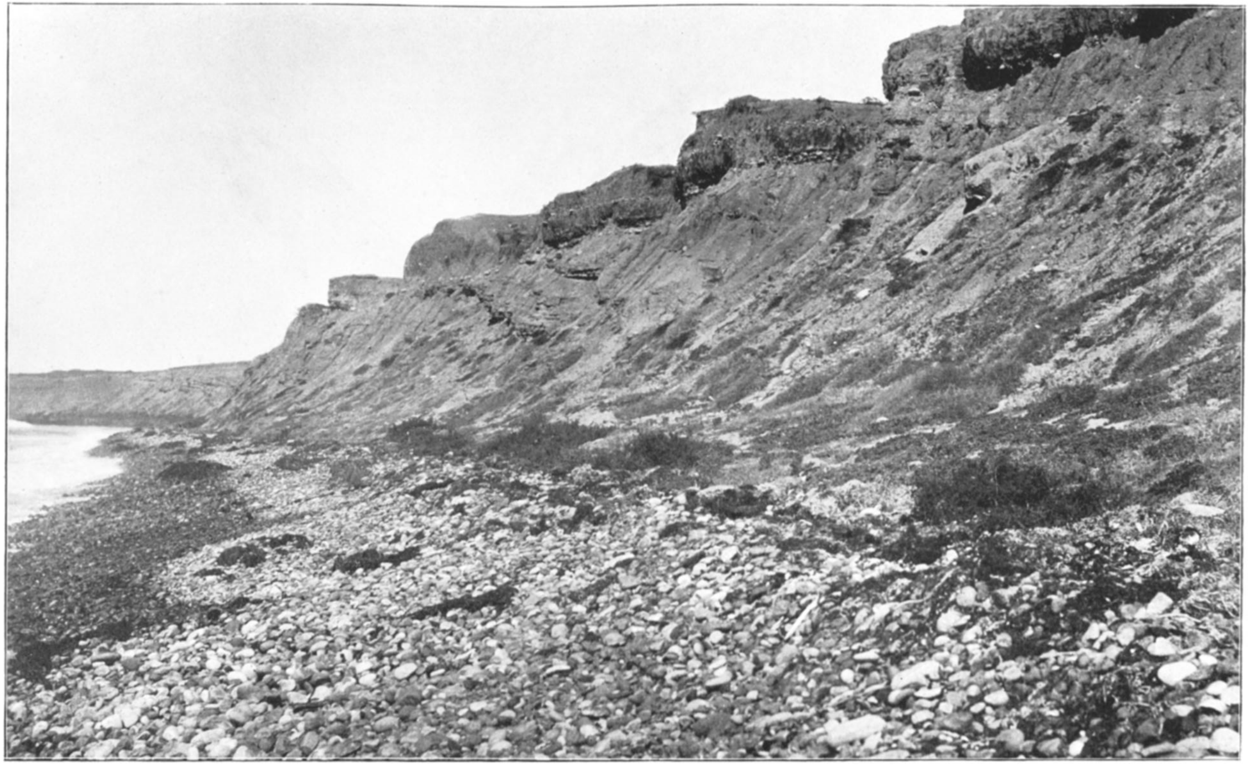
[1] The writers are indebted to Mr. Henry Hemphill, who collected fossils from the San Diego well during the course of its excavation, for the data concerning it.



Pacific Beach. San Diego formation (Pliocene) overlain unconformably by upper San Pedro (Pleistocene) gravels (see fig. 4 for explanation).

penetrates fossiliferous strata for its entire depth. The lowest beds are below the lower fossiliferous horizon of Pacific Beach, and are characterized by the large *Arca schizotoma* Dall (=*A. sulicosta* Gabb).

Pleistocene.—The tilted brown sandstone of Pacific Beach is overlain unconformably by a layer of fossiliferous gravel and sand from two to fifteen feet thick (see Fig. 4), which probably covers much of the terrace of which the Pacific Beach sea cliff is the bounding escarpment. In this respect the gravel layer is similar to the gravel stratum which covers the San Pedro terrace. The gravel and sand series is characterized by a fauna which is entirely different from that of the underlying sandstones, but which is almost identical to the fauna of the upper beds of San Pedro. Upon this evidence the gravel and sand layers are placed in the upper San Pedro series.

At the foot of Twenty-sixth street (see Fig. 5), and at Spanish Bight, beds of rather incoherent sands and fine gravels are exposed in the bluffs which form the shore line of the bay at these localities. These beds are richly fossiliferous, the fauna being similar to that of the upper San Pedro series at San Pedro, with which the Twenty-sixth street and Spanish Bight beds are correlated.

REGION BETWEEN SAN DIEGO AND SAN PEDRO.

The sea cliffs from a few miles north of Pacific Beach to near Newport are composed for the most part of soft dark colored shales and incoherent sandstones and gravels of late Pliocene and Pleistocene age. These deposits are mostly horizontal, but have been elevated in places to several hundred feet above sea level.

W. L. Watts[1] reports a formation, probably contemporaneous with the San Diego formation, at San Juan Capistrano in which the remains of a mastodon were found. Mr. Watts[2] has also reported deposits in the vicinity of Newport, which, from their fossil contents, have been correlated with the upper San Pedro series (Pleistocene) by the writers.

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[1] W. L. WATTS, "Oil-and Gas-Yielding Formations of California," *Bull. No. 19, Cal. State Mining Bureau*, pp. 59, 222, 1900.

[2] *Op. cit.*, pp. 61, 223.

At Bell Station,[1] near Los Angeles, a typical lower San Pedro (Pleistocene) fauna was obtained from a well between the depths of 920 and 1,320 feet. This shows the amount of sedimentation that has taken place in the Los Angeles basin during part of the Pleistocene epoch.

Gravels containing a typical upper San Pedro fauna are found at an elevation of about 350 feet on Los Cerritos Hill, near Long Beach (see map of San Pedro). The gravel stratum dips away from the top of the hill towards the ocean, and is part of the same series of sediments which is exposed in the sea cliff in front of Long Beach and Alamitos Beach (see Fig. 3).

REGION BETWEEN SAN PEDRO AND VENTURA.

The only locality between San Pedro and Ventura which has been examined by the writers is near Port Los Angeles. At this locality the sea cliff is nearly two hundred feet in height, the upper portion being composed of rather incoherent unfossiliferous sands and gravels probably of upper San Pedro (Pleistocene) age. These upper beds overlie, probably unconformably, hard strata of sandstone which contain a fauna similar to that found in the lower San Pedro series at Deadman Island.

VENTURA.

The most important fact about the geology in the vicinity of Ventura is the great thickness, steep inclination, and great elevation above the sea of the upper San Pedro (Pleistocene) sediments. The range of hills north of Ventura, which have an elevation of from five hundred to one thousand feet above sea level and which extend for several miles east and west of that city, are composed for the most part of soft, thickly laminated, yellowish-brown sandstones dipping away from the axis of the range. Along the old irrigating ditch which skirts the hills east of Matilleja Valley, west of Ventura (see Fig. 6), there is an

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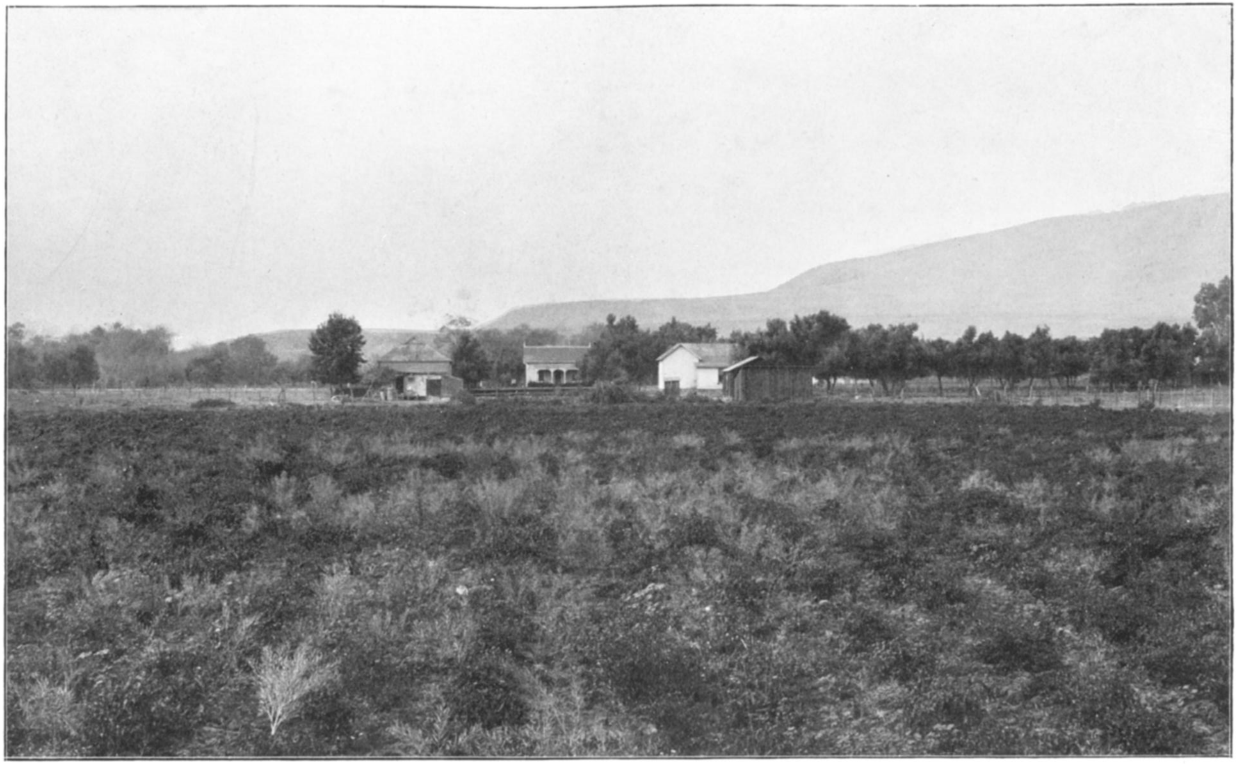
[1] W. L. WATTS, *op. cit.*, p. 233.

Plate IV.



Ventura. Wave-cut terraces in Pleistocene sediments one mile west of Ventura.

exposure of over one thousand feet of these soft sandstones, tilted at an angle of from 40 to 50 degrees toward the ocean. The fauna of these beds indicates their contemporanity with the upper San Pedro series, although the fauna near the bottom resembles more that of the lower San Pedro. A fauna of over sixty recognizable species was obtained from soft beds in the hills north of Barlow's ranch, three miles east of Ventura, at an elevation of between seven and eight hundred feet. The strata from which these fossils came are inclined at an angle of over 40°, but are not contorted. The fauna is typically upper San Pedro, all of the sixty species (with the possible exception of one which is a variety of a living species) being living forms.

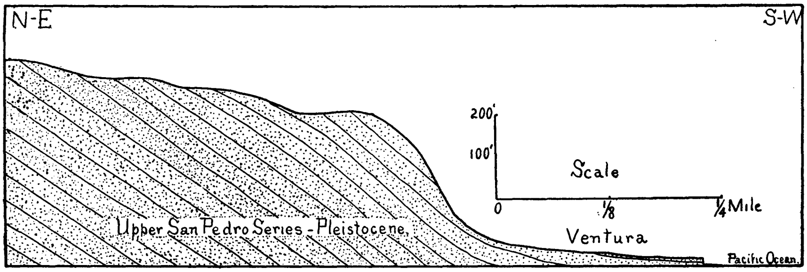


FIG. 6.— Section through Ventura, showing thickness of upper San Pedro series (Pleistocene) sediments, and a wave-cut terrace in the sediments.

Wave-formed terraces plane off the Pleistocene beds in the hills about a mile west of Ventura (see Plate 5). These terraces represent a period of time later than the upper San Pedro, and are probably of late Pleistocene age. The accumulation of comparatively great thicknesses of sediments, their elevation to at least one thousand feet, and their configuration by wave-cut terraces shows how active the geologic agencies have been in the vicinity of Ventura during comparatively recent times.

The region along the coast from Ventura to Santa Barbara is characterized by unfossiliferous, incoherent sands and gravels probably of Pleistocene age. Some of these sands and gravels are impregnated with asphaltum from the underlying Miocene shales.

SANTA BARBARA.

The later deposits in the vicinity of Santa Barbara resemble quite closely those of San Diego. At Packard's Hill, west of Santa Barbara, a thickness of over two hundred feet of alternating hard and soft beds of brown sandstone is exposed. These beds have a dip of S. 30° W. 50° toward the ocean. They are correlated by the writers with the Deadman Island Pliocene. Their fauna, however, shows a greater resemblance in some respects to the fauna of the San Diego formation (Pliocene).

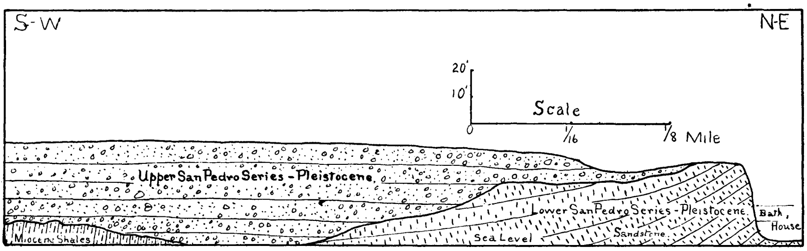
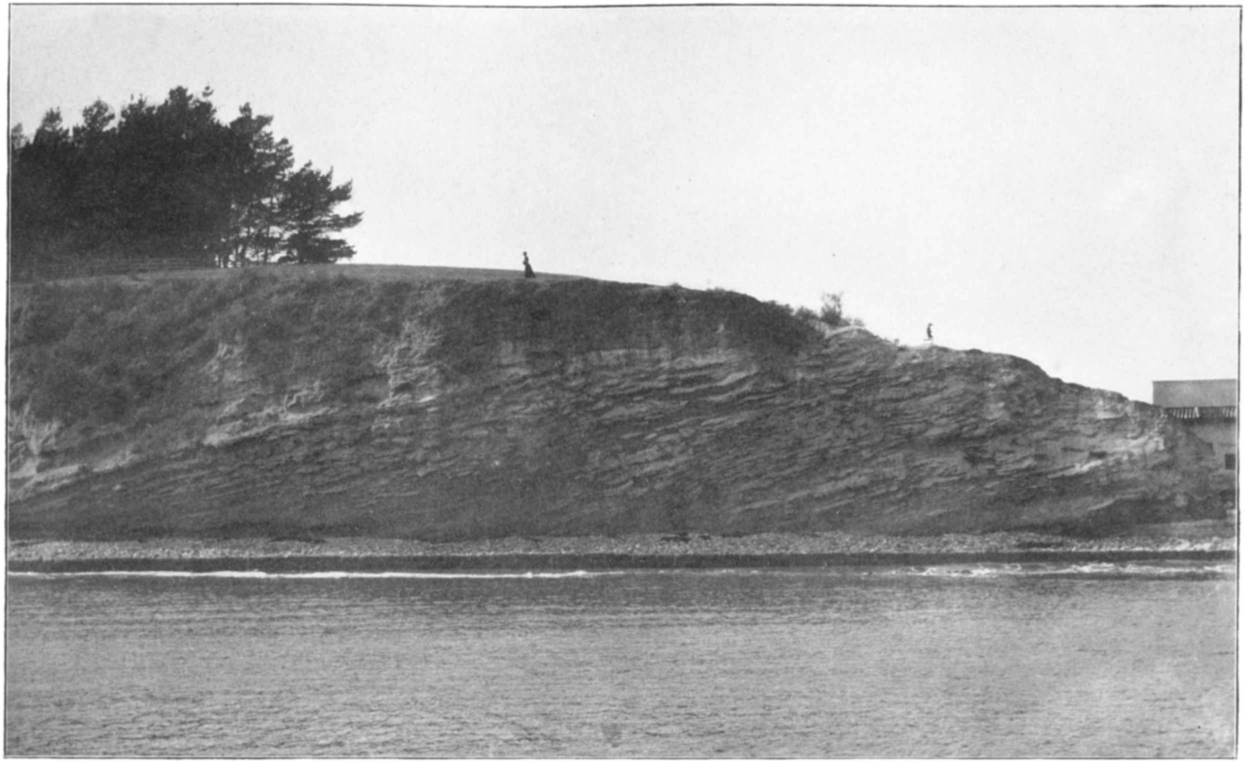


FIG. 7.— Santa Barbara. Section along coast southwest of bath house, showing relation between the Miocene and lower and upper San Pedro series (Pleistocene).

A thickness of thirty feet of alternating hard and soft beds of sandstone and sandy marl are exposed in the bluff west of the bath house on the Santa Barbara ocean front (see Plate V and Fig. 7). These strata are quite similar lithologically to the Packard's Hill Pliocene and probably lie conformably above it. The fauna of the bath house beach beds is more recent than that of the Packard's Hill deposits, and contain *Strongylocentrotus purpuratus*, *Echinarachnius excentricus*, and several other Pleistocene species not found in the Pliocene. Upon paleontological evidence the bath house beach deposits are correlated with the lower San Pedro series.

Beds of unfossilferous gravel and sand are exposed in the bluff west of the bath house beach fossiliferous strata. In some places these beds overlie the fossiliferous strata, while in others they overlie the basement series of Monterey shale. These sands and gravels, which are correlated with the upper San



Santa Barbara. Lower San Pedro (Pleistocene) strata west of bath house (see Fig. 7 for explanation).

Pedro series, are probably unconformable with the lower fossiliferous strata (a fossiliferous fragment of the latter being found in the former) although the exact relation between the two horizons was not definitely determinable stratigraphically, owing to the prevalence of false bedding in the upper beds. Asphaltum impregnates the gravels and sands in several places where they rest upon the Miocene shales. An Indian kitchen midden overlies the Pleistocene deposits one-eighth of a mile west of the bath house.

RELATION BETWEEN THE SOUTHERN CALIFORNIA PLIOCENE AND PLEISTOCENE AND THE MERCED SERIES.

A series of sandstones and shales over five thousand feet in thickness is exposed in the sea cliff which extends for a few miles south of Lake Merced on the San Francisco peninsula. This series of beds has been described by Dr. A. C. Lawson,[1] who named it the Merced series. Dr. Lawson places the whole series, with the exception of about one hundred feet of strata at the top, in the Pliocene. Dr. G. H. Ashley[2] draws the Pliocene-Pleistocene line further down in the series, or at the base of a fossiliferous stratum which has received the local name "upper gastropod bed." A study of the faunas of the different layers of the merced series has led the writers to draw the line in the same place that Dr. Ashley has drawn it. Although there is a distinct faunal break between the "upper gastropod bed" and the subjacent layers, there seems to be no indication of any decided interruption in the sedimentation in this part of the series.

Dr. Dall[3] places the San Diego formation, with which he correlates the Deadman Island Pliocene, below the Merced series. This does not agree with the conclusions arrived at by the writers after a study of the stratigraphy and faunas of the formations under discussion. The San Diego formation, with which are correlated the Deadman Island Pliocene and the Santa Barbara (Packard's Hill and bath house beach) formations are placed in the upper part of the Merced for the following reasons: (1) the strata of the Merced series wherever examined by the writers show much more contortion than the strata of the San Diego formation or its equivalents; (2) the fauna of Deadman Island Pliocene grades over by easy stages into the fauna of the Pleistocene with only a slight break between the two, thus precluding the possibility of the intercalation of such a distinctive fauna as that of the Merced series between the Deadman Island Pliocene (equivalent of the lower San Diego formation) and the San Pedro series (Pleistocene); (3) the occurence in only the very uppermost layers of the Merced series of *Echinarachnius excentricus*, which is found in the upper horizon of the San Diego formation; and the total absence of the common Merced echinoderm, *Scutella interlineata*, from the San Diego formation and all of its equivalents and overlying beds; (4) the abundance at the very bottom of the San Diego formation (in the lowest part of the San Diego well section only) of the typically characteristic middle Merced pelecypod *Arca schizotoma* Dall (=*A. sulicosta* Gabb).

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[1] A. C. Lawson, "The Post-Pliocene Diastrophism of the Coast of Southern California," *Bull. Dept. Geol., Univ. of Cal.*, Vol. I, pp. 142–50, 1892.

[2] George H. Ashley, "The Neocene of the Santa Cruz Mountains, *Proc. Cal. Acad. Sci.*, 2d Series, Vol. V, pp. 312–37, 1895.

[3] W. H. Dall, "Correlation Table of North American Tertiary Horizons," *Eighteenth Ann. Rep. U. S. Geol. Surv.*, Pt. II, p. 335, 1898.

The probability of an overlap of the time periods represented by different formations, Merced, San Diego, and San Pedro, is considerable; in fact the term Merced series, as used by Lawson, probably includes nearly, if not all, of the San Diego formation, and probably part of the San Pedro series.

The following correlation table gives the relation between the different formations of the Pliocene and Pleistocene of the coast of California as understood by the writers.

CONDITIONS PREVALENT DURING THE PLIOCENE AND PLEISTOCENE.

Basing the conclusions upon the evidence offered by the faunas of the Pliocene and Pleistocene formations it is seen that there has been a fluctuation of conditions along the California

CORRELATION TABLE

OF THE UPPER PLIOCENE AND PLEISTOCENE FORMATIONS OF SOUTHERN CALIFORNIA.

[NOTE. — Wave lines show conformability; straight lines, unconformability.]

TOTAL THICKNESS.	PLIOCENE.	PLEISTOCENE.				EPOCH.
	SAN DIEGO FORMATION. Lower.	Upper.				FORMATION.
		SAN PEDRO SERIES. Lower.		Upper.	RECENTLY RAISED BEACH'S.	
	MERCED SERIES.					
PLEISTOCENE. 70'. PLIOCENE. 180'.	San Diego well. 150'	Russ School. 50'		Foot of 26th street. 20'		SAN DIEGO SECTION.
				Spanish Bight. 20'		
	Pacific Beach (lower horizon). 180'	Pac. B. (up. hor.) 20'		Pacific Beach. 15'		
PLEISTOCENE. 100'. PLIOCENE. 50'.	Deadman I. 45'	Deadman Island. 12'		Deadman Island. 10'	D'man I. 4'	SAN PEDRO SECTION.
	Timm's Point. 50'	San Pedro Bluffs. 50'		Lumber yard. 20'		
				Crawfish George's. 3'		
		Los Cerritos Hill. 50'		Los Cerritos Hill. 20'		
				Long Beach. 50'		
PLEISTOCENE. 1000'+		Old irrigating ditch (?)		Old irrigating ditch. 1000'+		VENTURA SECTION.
				Barlow's ranch. 100'+		
PLEISTOCENE. 60'. PLIOCENE. 200'+	Packard's Hill. 200'+	Bluff at bath house. 30'		Bluff ¼ mile west of bath house. 25'		SANTA BARBARA SECTION.
				Bluff 2 miles east of wharf. 30'		
PLEISTOCENE. 350'±. PLIOCENE. 5000'+.	Section from Lake Merced to Mussel Rock below the "upper gastropod bed." 5000'+	"Upper gastropod bed" to nonconformity. 150'±		Strata above nonconformity ("terrace formation"). 200'±		LAKE MERCED SECTION.
MAXIMUM PLEISTOCENE. 1320' (BELL'S STATION). MAXIMUM PLIOCENE. 5000' (LAKE MERCED).	San Juan Capistrano.			Newport, Orange county.		OTHER LOCALITIES.
				Bell's Station, Los Angeles county. 1320'		
		Port Los Angeles, fossiliferous horizon. 50'±		Port Los Angeles, upper unfossiliferous beds. 150'		
				San Pablo Bay, Contra Costo county. "Oyster beds."		
				Fort Ross, Humboldt county.		

coast since the beginning of Pliocene times. The San Pablo (middle Neocene) and Merced faunas contain an abundance of such genera as *Arca*, *Dosinia*, *Pinna* and other southern forms which indicate that southern or warm conditions prevailed during the period of deposition of those two formations. Following the Merced (or, more strictly speaking, the middle of the Merced) comes the San Diego formation with its fauna of such northern species as *Pecten caurinus*, *Panomya ampla*, *Purpura crispata*, several species of *Trophon* and many other species indigenous to northern waters, which shows that northern or boreal conditions prevailed during the later Pliocene and early Pleistocene times. The transition from the boreal conditions of the late Pliocene to the semitropical conditions of the upper San Pedro series (typical Pleistocene) is indicated by the transition fauna of the lower San Pedro series. The upper San Pedro fauna contains so many southern species that it is safe to assume that conditions more nearly approximating those of the coast of Mexico at the present time, prevailed along the coast of southern California during that part of the Pleistocene in which the upper San Pedro beds were deposited. Since these latter strata were deposited a slight change has taken place, and the conditions now prevailing were inaugurated.

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